THE CONTRIBUTION OF THE POORER EAR TO BINAURAL INTELLIGIBILITY

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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
REPORT NUMBER 768
Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4305.08-3003DAC9.09

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SUMMARY PAGE

THE PROBLEM

To determine whether a person with one normal ear and one defective ear can perform satisfactorily on a speech-masked speech ("cocktail party") test.

FINDINGS

Hearing loss in the octave 2-4 kHz somewhat handicaps performance. No deterioration of performance was found if one ear was within normal audiometric limits on the average from 1-4 kHz and the other ear average was within 20 dB; but if the asymmetry was more than 20 dB deterioration was seen.

APPLICATION

Physical standards for "Normal Hearing" should include a test at least at one frequency in the octave above 2 kHz; and physicians examining personnel for unlimited Navy duty should carefully consider before acceptance those with audiometric asymmetries of 25+ dB on the average from 1 through 4 kHz.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit M4305.08-3003DAC9. The present report is Number nine on this work unit. It was submitted for review on 19 November 1973, approved for publication on 1 February 1974 and designated as NavSubMedRschLab Report No. 768.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

Two-hundred and fifty-three normal-hearing Navy enlisted men were examined in groups of 20 or less. Their speech reception was tested on a sentence intelligibility test masked by voices coming seemingly from R and L, (this stereophonic illusion is known as the "cocktail party" effect). Performance was not affected until the input to one ear was reduced by 25+ dB re the other ear. This rejection criterion of 25+ dB was corroborated on 92 patients with audiometric asymmetries. If this criterion is also found on other binaural tasks now being considered in this Laboratory, it will support a recommendation to exclude those with such asymmetries from certain Navy duties.

THE CONTRIBUTION OF THE POORER EAR TO BINAURAL INTELLIGIBILITY

INTRODUCTION

The data of this paper are concerned solely with the question of what contribution a defective ear may make to the better ear when a person listens binaurally to the "cocktail party" effect. In interpreting these data, one raises fairly ancient questions of what constitutes "hearing handicap," formulae to compute "binaural percentage hearing loss," and neural mechanisms of binaural fusion as they relate especially to interaural loudness disparity. These are discussed in the following order:

A. Hearing Handicap

A frequent question asked of otologists and those professionals involved in management and utilization of hearing-defective individuals is, what is the percentage of hearing handicap exhibited by a patient? Unfortunately, although an answer is always demanded and often extracted, and the patient understands and appreciates the numerical answer, this turns out to be irrelevant, as it has at the moment no real answer. The term "hearing handicap," as distinct from "hearing impairment" (which may be too slight or of such nature as not to constitute a handicap), and as distinct from "hearing disability" (which connotes job placement) is rather generally accepted now as denoting all aspects of audition in its role in everyday life. It has not as yet however been scaled by modern sociometric procedures so as to create a true ratio scale, much as attitudes and other aspects of social behavior have been. Thus there can as yet be no real quantification of "percentage hearing handicap," and the term is being dropped by careful thinkers.

A scale does of course exist, the decibel (dB) scale, for assessing an ear's sensitivity to any acoustic stimulus, and the audiogram is now universally used to delimit an ear's auditory field. With this scale, dB levels of sensitivity can be related to categories of hearing handicap, when these are arranged in an interval scale, and hearing handicap categories can be quantified in terms of a dB scale for each frequency, or a frequency range, of the pure-tone audiogram.

It is clear that certain low-frequency regions, and certain high-frequency regions, contribute little or nothing to most human interactions, whereas those frequencies most involved in speech intelligibility contribute relatively much more. However, the questions of which frequencies and their possible relative weights, are still being studied today, and by way of cutting the Gordion Knot there is by now close agreement that hearing handicap as a social condition can best be assessed by measuring hearing levels with actual speech as the test material. Two questions are, at what level does a handicap begin, and at what level is it total?

(1) Where Does Handicap Begin?

Many authors have suggested, based upon statistics of the normal curve and

upon clinical experience, that an ear with thresholds, either for pure tones or for speech, depressed more than 15 dB below norm, will have difficulty handling at least faint speech. A continuing question has been, what are the relevant norms? The recent ANSI standards for both pure-tone and speech audiometry have settled some older inconsistencies, but there are at the moment no national standards for hearing handicap in terms of actual speech tests. The Amer. Acad. of Ophthalmology and Otolaryngology (AAOO)[1] in 1969 revised its classes of hearing handicap (defined as ability to understand speech) in terms of average pure-tone thresholds at 500, 1000, and 2000 Hz in the better ear. (See Davis and Silverman[6].) An average hearing threshold level (HTL) of 26 dB (ISO) at 500, 1000, and 2000 Hz was said to initiate the mildest class of handicap. What is this 26 dB in terms of HL at 500, 1000, and 2000 Hz, for an SPL of 35.2 dB re .0002 μbar for the TDH-39 earphone $\left(26 + \frac{11.5 + 7 + 9}{3} = 35.2\right)$?

Now speech HTL is at 20 dB re .0002 μbar, and to a close approximation, then, the AAOO system starts its handicapped classes at about 35.2 - 20 = 15.2 dB HL (rounded to 15) for SRT derived from actual speech.

(2) <u>Where Does Handicap Become Total?</u>

Fowler[9] in his extensive otological practice considered this question as fully as anyone ever has. He did not have adequate speech audiometry available, but he concluded that if one weighted hearing losses in dB on the audiometer by .15, .3, .4, and .15 at .5, 1, 2, and 4 kHz respectively, a weighted loss of 100 dB could be considered total loss of hearing for speech. The Amer. Med. Assoc. followed Fowler's method with only slight modification: HLs for total loss were set at 90, 95, 95, 95 dB for the four frequencies separately. More recently, the AAOO[1] has set its "total loss" at 93+ dB (ISO) for the 3-tone average HL. This represents $93 + \frac{11.5 + 7 + 9}{3} = 102.2$ dB SPL or an equivalent 82 (rounded) dB HL for actual speech. Thus a range of 15 - 82 dB exists between the speech HL at which handicap starts and the HL at which it is complete.

One approach, statistically unjustified but helpful in certain instances, is to compute "percentage hearing loss" by a nomograph such as in Fig. 1, where 15 dB HL for speech represents 0% and 82+ represents 100%.

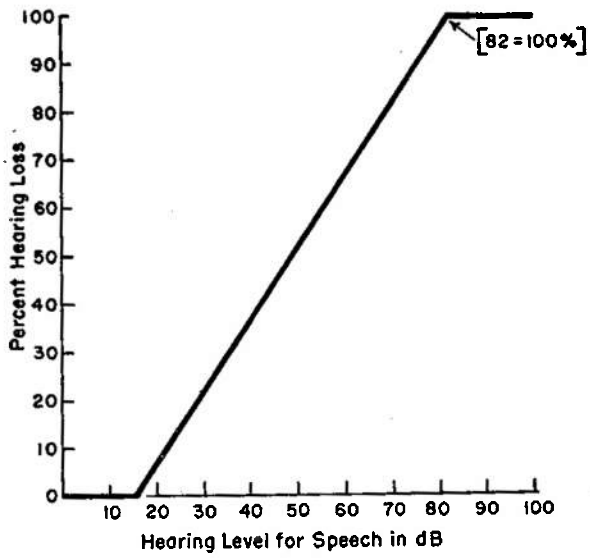

Fig. 1: Relation Between Hearing Level for Speech in an Ear and Percentage of Hearing Handicap for that Ear.

(3) Problems with Using Actual Speech to Assess Hearing Handicap.

There are a number of problems in describing an ear's speech-handling capacity solely in terms of its SRT. In the first place, in those days when the SRT could only be estimated by the pure-tone audiogram, Fowler[9] felt that variable credit should be given for the demonstrated presence of mild recruitment, and credit removed for more severe sensorineural losses.

In the second place, Davis[5] noted that the SRT of an ear may perhaps describe its capacity at threshold, but that louder speech may not be progressively much more intelligible and for such a condition he coined the technique of the still-unstandardized "Social Adequacy Index."

In the third place, assessing the SRT with actual speech being impossible with certain persons, and fraught with special problems of speech material, etc., the AAOO[1] has most recently recommended that pure tones still be used widely to assess SRT.

B. The Contribution of the Poorer Ear

If however the hearing handicap ascribed to a particular hypacusic ear can even now be stated quantitatively only with some constraints, the hearing handicap experienced by the whole patient is yet another matter. The American Medical Association originally used a 7:1 ratio (per cent loss for speech in better ear X 7, added to per cent loss for speech in worse ear, ÷ 8), it was however clear even then that the poorer ear does not contribute according to a fixed ratio for all HLs of the better ear, since the poorer ear is less important as it is more defective, while the better ear gets relatively more important as it is more defective. Fowler developed a variable ratio method which he conveniently cast into tabular form (see Table III in Fowler, 1974, p. 482). For example, symmetrical losses of 40 dB in each ear yield a binaural per cent loss of 35 dB. If however one ear has 100% loss the figure drops by 16% to 51%; while symmetrical losses of 80 dB yield a binaural per cent loss of 93%, though if one of the ears has a 100% loss, the binaural score drops only 4 points to 97%.

Entries in this table were changed and revalidated over many decades by Dr. Fowler, Sr., and should be seriously considered.

At the present time, the AAOO computes binaural hearing handicap simply by adding 5 dB to the 3-tone average HL of the better ear if the poorer ear is 25 dB or more below the better ear. Thus, if a patient has in his better ear a 3-tone average HL within 20 dB of "Normal," he gets no consideration either for the defect in his better ear or for being stone deaf in the other ear (Fowler's method would assign a 20% handicap).

None of these monaural-binaural systems have ever been based upon any experimental evidence whatsoever, but were usually committee judgments where the opinions of one or two dominant otologists would supervene.

C. The Neurophysiology of Binaural Hearing.

This is now a topic of a rapidly expanding literature. Here it will only be pointed out that the common statement of there being a 3-dB binaural advantage at threshold for symmetrical ears must be supplemented by other considerations. For example, Decroix and Dehaussy[7] found a binaural advantage of up to 7 dB at suprathreshold loudness; Irwin[12] found binaural advantage to increase as overall loudness increased. In another example, Koenig[13] noted that unwanted sounds dichotically presented to his ears were "squelched" in comparison to the wanted signal diotically presented. In the laboratory this "binaural unmasking" of a signal in a noise, where both are presented diotically to the two ears of a normal person, and either of them is reversed in phase by 180° whereupon the signal leaps into prominence, can reach as much as 15 dB or more. For other random examples: MacKeith and Coles[15] showed a binaural advantage for speech in noise even where one ear was lower than the other by 39 dB; while Bergman[3] found binaural advantage in localizing sounds even with one ear defective by 35 dB.

Evidently the auditory nervous system is set up to process not just the inputs from two ears simultaneously, but the two inputs as they interact in the central nervous system.

Dobie and Simmons[8] had normal Ss report which initial consonant (p, t, k) they heard in an attended ear. To the unattended ear one of the other two consonants was delivered simultaneously at 75 dB SPL. When the consonant to the attended ear was equally as intense as that to the unattended ear, Ss had no difficulty; but when the consonant to the attended ear was down relatively by 20.5 dB (for 17 R-handed Ss) or 15.05 dB (for 16 L-handed Ss) the mean performance dropped to 50% correct. Thus a phoneme weaker by 15-20 dB in one ear than in the other can still have an effect on intelligibility.

With brain-damaged Ss, these authors found that some could attend to one ear only when the input to that ear far exceeded the other in intensity. Thus a binaural arrangement can with some Ss yield an abnormally high masking and lowered intelligibility.

Cherry[4] and colleagues[16] had suggested that if the speech inputs to the two ears had different types of distortion the normal-hearing S might not meld them, while Arkebauer et al.[2] found that monaural speech reception in a free field was worse than binaural and that the more defective the better ear, the more degradation the other ear occasioned. McGraw and Craig[14] report another case, of a young man, mentally retarded but said to be neurologically normal, who could function well only with an earplug in one ear.

One may, from this rather extended line of reasoning, now ask specific questions that are open to experimental attack: In a situation involving speech diotically presented to the two ears of persons, but masked by competing speech presented dichotically (this is the so-called "cocktail party" situation, a common occurrence is nearly everyone's daily life), how much improve-

ment does a second ear of equal sensitivity add and how much improvement is lost as the second ear falls off in sensitivity?

In previous papers in this series we have shown that the cocktail party effect can yield an advantage of two normal ears in the Stereo Mode (50.5% words correct) over the Monaural Mode (23.7%) of 50.5 - 23.7 = 26.8 percentage points, and for defective listeners (where the asymmetry was compensated by a hi-fi amplification) the stereo advantage was 47.6 - 29.1 = 18.5 points[10]. In a second paper[11] the binaural advantage was also of the order of 25 percentage points over a major portion of the psychophysical function, both for normals and for monaural hypacusics (again with defect compensated by amplification (see Figure 2)). In this third paper we used the same tapes again for the cocktail party effect, but allowed the defective ear, whether artifically reduced by attenuation, or reduced by reason of clinical hypacusis, to contribute as it might.

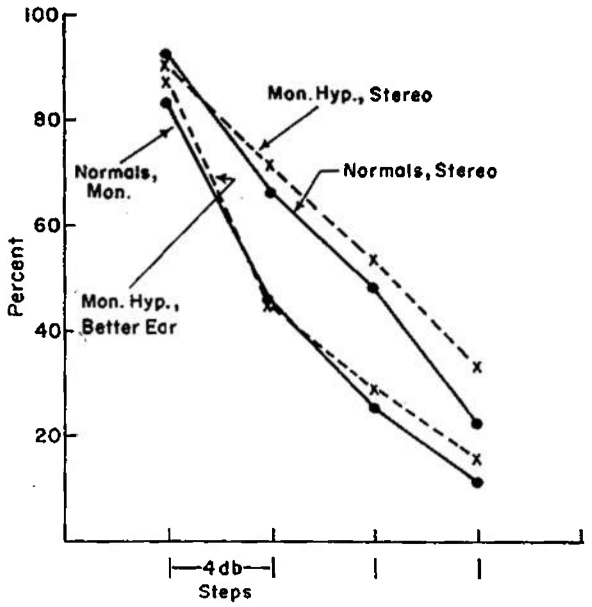

Fig. 2. Percent Words Correct Vs Signal-Noise Ratio for Normals and for Monaural Hypacusics in the Monaural and Stereo Modes (From Harris and Myers[11]).

METHOD

Normal-hearing candidates for Submarine School were selected from groups detailed to this Branch for audiometry. No subject(s) had HL greater than 15 dB through 8 kHz. There were also 92 monaural hypacusics from our audiology clinic. The test room was a soundproof chamber with 20 chairs, a set of 20 monaural R phones closely matched for frequency-response characteristics, and another set of 20 monaural L phones closely matched within the set.

Tapes of the "cocktail party" type[11] were used to assess the advantage of the second ear. For this test, in the Stereo Mode, one voice seemingly in the midline repeats the CHABA C.I.D. colloquial sentences (slightly revised at NSMRL to equate length among the 10 sentences of a list and recorded here with a single experienced male talker), while a man and a woman seemingly at the R and L ears respectively read interesting materials. Ss listened to Test B at 60 dB Sensation Level (SL) monaurally only in their best ear, and to Test C also at 60 dB SL in their better ear, but (1) in the case of monaural hypacusics with the two earphones matched at 60 dB SL, and (2) in the case of normal-hearing Ss, monaural hypacusis was simulated with attenuation of 0-50 dB inserted at one ear.

On our Test B too many normals score 100% to render it usable for our present purposes. On the other hand, too many normals score 100% when Test C is given in the Stereo Mode; to avoid ceiling effect we were forced to use Test C in the Stereo Mode in order to examine the distribution for a binaural test.

Normal-hearing Ss were tested in groups of 20 or fewer; patients were tested individually. After each sentence the tape was stopped and Ss given ample time to write the sentence as best they could.

Test B was at a + 2 dB more favorable signal/noise ratio than Test C and was given to assure that all groups were of equal competence at this sort of task. Test C was thus more difficult and avoided for the most part the "ceiling effect."

RESULTS AND DISCUSSION

A. Normal-Hearing Ss.

The distribution from the 253 normal Ss on Test B is in Table I. None of the 14 groups of 15-20 Ss examined yielded results reliably different from the mean. We conclude that all groups were comparable in ability to interpret speech-masked speech, and hence their data has been pooled.

Table I. Percentage Key Words Correct for Test B for Normals in the Monaural Mode

Score	N	
95-99	19	Intensity: 60 dB Sensation Level
90-94	89	Mn: 86.78
85-89	53	S.D.: 8.05
80-84	51	S.E.: 1.59
75-79	21	Range: 52-98
70-74	10	
65-69	3	
60-64	3	
55-59	1	
50-54	2	

The first group was given Test C in the Stereo Mode, each ear circuit set to the same level as for the Monaural Test B. Subsequent groups always heard with one ear at this level, but the other ear circuit was reduced by 10, 20, 30, 40, and 50 dB. Control groups were also run monaurally on Test C, set at the same level at the fainter ear in the Stereo Mode. These data are in Table II and Figure 3.

One major point can be made in Figure 3. The stereo advantage at a comfortable listening level is 16.5 percentage points and an advantage is maintained (about 10 points) even when one ear is reduced by about 20 dB. This advantage however is lost when

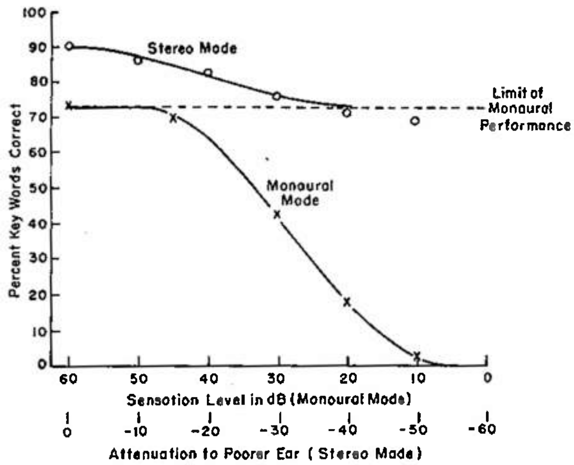

Fig. 3. *Percent Key Words Correct Vs Sensation Level in the Monaural Mode and Audiometric Asymmetry in the Stereo Mode for 243 Normal-Hearing Listeners.*

Table II. Percentage Key Words Correct for Test C for Normals

Level in SL in: Stereo Mode					Monaural Mode			
Better Ear	Poorer Ear	N	Mn	S.D.	Level in SL	N	Mn	S.D.
60	60	20	89.9	5.34	60	36	73.4	11.32
60	50	19	86.7	8.49	45	32	70.7	11.56
60	40	20	83.1	10.02	—	--	----	-----
60	30	18	76.8	7.78	30	15	43.5	6.04
60	20	18	71.9	8.19	20	19	18.7	13.76
60	10	36	69.4	11.95	10	20	4.0	-----

one ear is reduced by almost 30 dB. Thus one may conclude that, for persons with no auditory pathology, an audiometric asymmetry of 20 dB will have a negligible effect on their reception of speech-masked speech. Provisionally one could recommend that if one ear is within audiometrically normal limits, the other ear could, if it exhibits no especial pathology, be depressed through the speech range by 20 dB on the average and the candidate be considered perfectly capable of understanding speech-masked speech.

B. Monaural Hypacusics.

The possibility must be considered that these data apply only in a limited extent to cases of actual hearing loss. To test this, we examined 91 monaural hypacusics appearing in our audiology clinic with Tests B and C, in addition to the usual AC and BC audiometry, Speech Reception Threshold (using the Phonetically Balanced words) and the PB Discrimination Score (DS) at 40 dB SRT.

A first question was, by which aspect of the audiogram may we characterize an ear to relate to performance on our Tests B and C. We initially used the average Hearing Level (HL) at 0.5, 1, and 2 kHz. When on Test C in the Stereo Mode we examined 39 normal Ss in whom both ears were at a 3-Ave HL of 10.0 dB or better, the average score was 88.8% key words correct (S.D. = 7.65). But of 17 of our 92 patients in whom both ears were at a 3-Ave HL of 10.0 or better, the average score was only 73.99 (S.D. = 12.75). Thus, those patients with "normal" audiograms by the usual 3-Ave test were deficient in ability at interpreting speech-masked speech and the question arises, is it possible that frequencies higher than 2 kHz contribute to this ability?

We computed the average HL at 1, 2, 3 and 4 kHz and found 14 patients with the better ear average HL at 1-4 kHz of 10.0 or better, the other ear worse by no more than 20 dB. For these, the mean score in the Stereo Mode was 86.5% key words correct; this is indistinguishable from the mean of those normals with ear asymmetry of 20 dB or less (see Table II), and persuades us that it is necessary to consider the octave 2-4 kHz in identifying a person's ability to handle speech-masked speech. For the rest of this paper, the definition of an ear's HL will be the 1-4 kHz average.

When one compares the performance of those 19 patients with one normal ear and an audiometric asymmetry of 20 dB or less, with the performance of 90 normals who were given Test C in the Monaural Mode (including two groups who were given the Stereo Mode but the poorer ear was reduced to an ineffectual asymmetry of 40 and 50 dB), no difference existed: the 14 patients yielded a mean score of 78.8 (S.D.: 12.85) while the 90 normals yielded a mean of only 72.0 (S.D.: 11.35), a difference favoring the patients. Thus we can assign no deterioration to a patient with one normal ear and an audiometric asymmetry of 20 dB or less.

When one compares for the Stereo Mode of Test C the performance of those 32 patients with one normal ear (1-4 kHz HL < 10.1 dB) but (1) the other ear relatively defective by 20 dB or

less (N: 13) compared (2) with those having 20.1 dB or more (N: 19), a significant difference appears in favor of those with the greater symmetry (86.5 vs 78.80%; but significant only at the 10% level).

There is thus a tendency for the clinical material to corroborate the normal material, in that performance is definitely worse when one ear is depressed more than 20 dB re the normal ear, but the evidence is not very striking.

There were 35 patients for whom the better-ear average at 1-4 kHz was 10.1 - 20.0 dB HL; for these, the performance on Test C in the Stereo Mode had dropped significantly to about the level for the normals in the Monaural Mode (mn = 72.0 $\pm$ 1.2) whether the ear asymmetry were 20 dB or less (N: 20, mn = 73.5 $\pm$ 2.68) or more than 20 dB (N: 15, mn = 70.5 $\pm$ 6.17). From these patients one cannot conclude that the greater asymmetry would not in other situations yield some stereo disruption, since the better ear had set, not a ceiling on, but a floor under, the performance.

On our 15 patients with a better-ear 1-4 kHz ave HL of 20.1 - 30.0, too few had asymmetries greater than 20 dB to warrant similar analysis.

Inasmuch as our test repertoire was confined to a single Test C at the S/N ratio, we were unable to make in this particular study a direct comparison of the Monaural-Stereo difference for different amounts of asymmetry. We attempted to compare the Monaural Test B performance on each patient with the Stereo Test C performance, but (1) ceiling effects and also (2) cellar effects, (3) variability in performance on each list, and (4) primarily patient-list interactions (such that some patients performed much better on the harder Test C in the Stereo Mode than would have been predicted from their performance on the easier Test B in the Monaural Mode), all combined to obscure the Stereo advantage for degrees of asymmetry.

These data can be interpreted to mean that on one type of binaural test an audiometric asymmetry of more than 20 dB is a handicap, though only of moderate severity. It would of course be premature to recommend on the basis of these results alone that such asymmetries should be excluded from a specialized population such as the Navy. In the first place, this study should be extended to examine the stereo advantage more directly in a clinical population. Furthermore, other situations should also be considered in which binaural asymmetries could be detrimental, such as directionality, the discrimination of acoustic cues in troubleshooting equipment in background noises, etc. Research along these lines is continuing in this Laboratory.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D	
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)	
1. ORIGINATING ACTIVITY (Corporate author) NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY Naval Submarine Medical Center	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP
3. REPORT TITLE THE CONTRIBUTION OF THE POORER EAR TO BINAURAL INTELLIGIBILITY	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Interim report	
5. AUTHOR(S) (First name, middle initial, last name) J. Donald Harris, Ph.D. and Cecil K. Myers	

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
1 February 1974	10	16

8a. CONTRACT OR GRANT NO. b. PROJECT NO. M4305.08-3003DAC9.09 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NSMRL Report Number 768 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Submarine Medical Center Box 600 Naval Submarine Base Groton, Connecticut 06340

13. ABSTRACT

With 253 normal-hearing Navy enlisted men examined in groups of 20 or fewer, speech reception was tested on a sentence intelligibility test masked by voices coming seemingly from R and L (by the stereophonic illusion; this is the well-known "cocktail party" effect). Performance was not affected until the input to one ear was reduced by 25+ dB re the other ear. This rejection criterion of 25+ dB was corroborated on 92 patients with audiometric asymmetries. If this criterion is also found on other binaural tasks now being considered in this Laboratory, it will support a recommendation to exclude those with such asymmetries from certain Navy duties.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hearing Standards						
Stereophonic Illusion						
Audiometric Asymmetry						
"Cocktail Party" Effect; hearing among many voices						

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(PAGE 2)

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